Edwards SJ, Emmerson C, Namdeo A, Blythe PT, Guo W.

Optimising Landmark-Based Route Guidance for Older Drivers.

***Transportation Research F: Traffic Psychology and Behaviour* 2016, 43, pp.225-237.**

DOI link to article:

http://dx.doi.org/10.1016/j.trf.2016.10.017

Date deposited:

14/11/2016

Transportation Research Part F 43 (2016) 225–237

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

Optimising landmark-based route guidance for older drivers

S.J. Edwards *, C. Emmerson, A. Namdeo, P.T. Blythe, W. Guo

Transport Operations Research Group, University of Newcastle upon Tyne, UK

ARTICLE INFO

Article history:
Received 4 March 2016
Received in revised form 12 August 2016
Accepted 9 October 2016
Available online 1 November 2016

Keywords:
Older drivers
Navigation
Information
Landmarks
Gender

ABSTRACT

In-vehicle navigation systems (IVNS) have the potential to benefit older drivers, reducing stress associated with way-finding and providing on-trip support, especially in unfamiliar locations. However, existing IVNS present challenges to usability, resulting in lack of uptake and over-reliance on pre-trip planning.

This paper presents research aimed at identifying features that make IVNS user-friendly and appropriate for older drivers. Studying navigational performance within a simulated driving environment, it focuses on the use of landmarks with route guidance information, and the most appropriate method of information provision (audio only, visual only or a combination of audio and visual). It also assesses potential gender differences that might arise with landmark-based navigational information.

Solutions include use of appropriate roadside landmarks, and information delivered through a combination of audio and icon-based visual format. These features result in lower workload and fewer navigational errors. The audio/visual modality reduces the hazard of distraction by landmarks resulting in fewer visual glances and lower glance duration to the roadside compared to other modalities.

Design and provision of IVNS tailored to older drivers' needs can make a considerable contribution to maintaining individual mobility for longer.

1. Introduction

Navigation, in its broadest sense, is to travel safely, efficiently and independently from one point to another (Burns, 1999; May, Ross, & Osman, 2005). It may involve two distinct but often interrelated themes: pre-trip planning and way-finding. Pre-trip planning encompasses the navigational preparations many (but not all) people make before undertaking a journey, whereas way-finding can be defined as the on-trip decision-making process the driver is required to undertake to reach their destination (Burns, 1999).

Navigation involves multi-level cognitive processing and attracts much theoretical and practical interest (Ishikawa, Fujiwara, Imai, & Okabe, 2008). Older adults often experience difficulty in navigating because age-related decline in cognitive, perceptual and motor skills (including spatial learning and memory) can impede the mental representation of a spatial environment (Forlizzi, Barley, & Seder, 2010; Kim, Hong, Li, Forlizzi, & Dey, 2012; May et al., 2005; Yamamoto & DeGirolamo, 2012). Therefore, older adults may face challenges in navigating a journey from memory. Moreover, they will often want to avoid certain situations like heavy traffic, driving at night or driving on unfamiliar routes – a process called self-regulation (Burns, 1999; Charlton, Oxley, Fildes, Oxley, & Newstead, 2003; Rabbitt, Carmichael, Jones, & Holland, 1996). Older drivers

* Corresponding author.
E-mail address: simon.edwards@ncl.ac.uk (S.J. Edwards).

http://dx.doi.org/10.1016/j.trf.2016.10.017
1369-8478/

often plan alternative ways of achieving their goal or adapt their behaviour in order to reach a required destination (Banister & Bowling, 2004; Metz, 2000, 2003).

Bryden, Charlton, Oxley, and Lowndes (2013) conducted a large-scale survey with 534 drivers aged 65 and over to examine their way-finding strategies and navigational behaviour. From this sample, 60% of the participants reported difficulties with way-finding. When reviewing strategies for an unfamiliar journey the researchers found that using a map while driving was the most popular (62%), reading a map while on the roadside was second (55%) and reliance on memory (38%) third. 33% of older drivers would create written instructions or a drawn map to assist them. Only 10% would use an in-vehicle navigation system (IVNS). Moreover, this research found that when older drivers have difficulties with way-finding they are likely to ask a passenger to assist them in the navigation task.

1.1. Older drivers and IVNS

In Vehicle Navigation Systems (IVNS) can benefit older drivers as they assist with the pre-trip planning and way-finding tasks of driving (Burnett & Lucas, 2010). However, they are not widely used by this demographic with older drivers more often navigating with conventional maps complemented with written notes (Bryden et al., 2013; Musselwhite & Haddad, 2010). Yet the scope for using conventional maps to plan and then way-find a journey is restricted, as paper maps cannot provide the current location, rather the driver interprets his/her location from the map. When relying on paper maps, a driver will observe landmarks and keep them in his/her working memory, using them to determine current location (Daimon & Kawashima, 1995).

IVNS generally provide the current location on a map-based visual display along with the estimated arrival time and distance to next turn. As the visual display operates at all times, it is not necessary for a driver to retain information in his/her working memory. Drivers will still search for landmarks but determine that they are on the correct road by observing the visual display. This reduces the need for a cognitive map, that is, a mental representation of the spatial environment and use of this representation to navigate that environment (Chown, Kaplan, & Kortenkamp, 1995; Kitchin, 1994; Lynch, 1960). Cognitive maps can be more challenging for older adults because of age-related decline in cognitive skills, spatial learning and memory (Iaria, Palermo, Committeri, & Barton, 2009; Liu, Levy, Barton, & Iaria, 2011).

Visually, an IVNS can be either a moving map display or an icon-based display. However, display complexity and visual demand can be a challenge for older drivers. In a simulator study where drivers of all ages followed a route on an IVNS, the older drivers' mean glance duration towards the display was 0.98 s, compared to the younger drivers' average of 0.84 s (Zhang, Wang, Jia, & Dong, 2012). An on-road trial with 32 participants found that older drivers' mean glance towards a moving map-based display was 1.08 s compared to the younger participants' 0.83 s (May et al., 2005). There are clear implications in these findings for driver workload, distraction and safety imposed by a moving-map format (Birrell & Young, 2011; Pak, Czaja, Sharit, Rogers, & Fisk, 2008).

Supplementing the visual component are distance-to-turn audio instructions. Spoken instructions are crucial to safe and effective IVNS (Dalton, Agarwal, Fraenkel, Baichoo, & Masry, 2013), whilst for older drivers, audible information is preferable to the visual display in terms of reduced visual and cognitive demand (Jensen, Skov, & Thiruravichandran, 2010; Moldenhauer & McCrickard, 2003).

1.2. Navigation with landmarks

Landmarks are vital in determining orientation and current location. Lynch (1960) described landmarks as external reference points that are easily observable. Other researchers have provided alternative definitions, but a consistent finding is that landmarks are a useful form of navigational information, acting as a tool to understand spatial surroundings and navigate the environment (Nothegger, Winter, & Raubal, 2004; Roger, Bonnardel, & Le Bigot, 2011).

Underpinning this research is work by Burnett (1998) that produced a list of the top ten scoring landmarks based on a number of questionnaire-based and road trial-based studies, and geographic location. The resulting landmarks are specific to the UK: traffic lights, pedestrian light-controlled crossing ('Pelican'), bridge over road, hump-backed (arched) bridge, petrol station, monument, superstore, street name sign, railway station, and church. A further study (Burnett, Smith, & May, 2001) involved 32 participants (16 male, 16 female; age range 22–60) who were asked to write down detailed route plans for an unfamiliar journey. This aimed to understand the characteristics of what makes a good landmark for navigation. The frequency of landmark mentions was analysed, and the contextual differences of the landmark types assessed. The research thus proposed characteristics of 'good' landmarks as permanence, visibility, usefulness of location, uniqueness, and brevity (see Table 1).

Adopting the findings of Burnett et al. (2001), May et al. (2005) conducted an on-road trial to investigate the benefits to older and younger drivers in providing landmarks with audible route guidance information, finding that landmarks reduced the time spent glancing at the visual display, reduced navigational errors and positively influenced driver confidence, for both older and younger drivers. The authors concluded that the inclusion of landmarks could have significant benefits for older adults.

May and Ross (2006) implemented a road trial with 48 drivers aged over 21 using an IVNS providing visual arrows and verbal landmark information, as well as a visual map display. This study found that 'good' landmarks enhanced navigational performance, driving performance and confidence. In comparison, distance-to-turn information increased visual glances

Table 1
Characteristics of landmarks for navigation (Burnett et al., 2001).

Attributes of visible landmarks	Good landmarks	Poor landmarks
Permanence – the likelihood of the landmark being present, either in form or label	Churches, woods, monuments, schools	Factories, shops, petrol stations
Visibility – whether the landmark can be clearly seen in all conditions	24 h petrol stations	Post boxes, street names
Usefulness of location – whether the landmark is located close to navigational decision points	Traffic lights, corner shops	Rivers, railway lines
Uniqueness – the likelihood of the landmark not being confused with other objects/features	Bridges, roundabouts, railway stations, parks	Garages, traffic lights
Brevity – conciseness of description associated with the landmark	Traffic lights	Large white house on the left

towards the display. It also found that there was no impact on subjective workload when providing different navigational information to the driver. The authors concluded that future navigation systems should adopt a hybrid approach where distance-to-turn information is utilised only when an adequate landmark is not available.

1.3. Rationale for investigation

Navigation, especially way-finding, becomes more difficult as people age because of cognitive load. Older drivers therefore often restrict the amount they drive, notably on unfamiliar routes (Guo, Blythe, Edwards, Pavkova, & Brennan, 2015; Guo, Brake, Edwards, Blythe, & Fairchild, 2010). This can reduce mobility and ultimately health and wellbeing. Existing IVNS are difficult to use for many older drivers and result in increased workload and navigational errors. The design of IVNS does not seem to take into account age-related decline (Musselwhite & Haddad, 2010).

This paper builds on that of Emmerson, Guo, Blythe, Namdeo, and Edwards (2013) which analysed how older drivers plan and navigate a journey, their route guidance requirements, and the usability of IVNS. The information, collected from focus groups, revealed that uptake of IVNS by older drivers is low because of information delivery via moving-map displays and distance-to-turn audio instructions, which can have implications for workload, distraction and safety. Older drivers, therefore, have a navigation need that is not met by current generation IVNS. Specifically, Emmerson et al. concluded that alternative audio information and the use of landmark-based icons might present a more appropriate means of information delivery.

This research was valuable because there had been no prior clarity about how older drivers plan and navigate a journey. Without this information, their route guidance requirements could not be clearly determined and future IVNS could not be designed taking account of their needs. Furthermore, previous IVNS research utilised first generation or turn-of-the-century models; Emmerson et al. investigated usability of more up-to-date models. Finally, only a limited number of studies have investigated landmarks with route guidance information and those mostly from the perspective of the landmarks themselves (e.g. what makes a 'good' or 'poor' landmark) (Burnett, 1998; Burnett et al., 2001; May et al., 2005; May & Ross, 2006). There has been limited focus on older drivers, and there is currently no definitive evidence of the most effective way to present such information to older drivers in IVNS.

The research undertaken and presented in this paper investigates navigational performance of older drivers when provided with landmark-based route guidance within a simulated driving environment. It investigates in detail different modalities for information provision (audio only, visual only, combination of audio and visual), performing analysis of visual glance behaviour, navigational errors and workload. The research seeks to contribute, through practical experimentation, to greater understanding of the navigation function and IVNS needs of older drivers. Ultimately, the design and provision of IVNS tailored to older drivers' needs can make a considerable contribution to maintaining individual mobility for longer.

2. Experimental design

2.1. Objectives

The objectives of the research were:

- To study older drivers' navigational performance when provided with landmark-based route guidance information.
- To investigate the most appropriate method of delivering landmarks along with route guidance information (audio only, visual only, or a combination of audio and visual); and,
- To ascertain any potential gender differences with the provision of landmarks as navigational information.

A key feature of usability and safety of IVNS for any user is that the driver's attention is required while the vehicle is in motion. Quantification focused on visual glance analysis, navigational errors, and workload.

(a) Visual glance analysis (frequency, duration, allocation)

Roadside landmarks and in-vehicle displays can result in driver distraction from the driving task. Rockwell (1988) proposed that drivers should not take their eyes off the road for longer than two seconds. This clearly limits the amount of information a driver can obtain from a visual display. Visual glance analysis quantifies the number and duration of glances the driver needs to obtain the information from a screen or to identify a roadside landmark. The glance allocation of the driver results in a clear review of the visual scene (Green, 1993). Glance duration and frequency allow the researcher to indicate the percentage of journey time spent glancing towards the screen or landmark. Recording visual glance behaviour has become more achievable with the development of eye-tracking technology (Cairns & Cox, 2008) and has been found to be particularly beneficial when considering the effect of in-vehicle systems on older adults (Kim & Son, 2011).

(b) Navigational errors

To navigate effectively, the driver must reach his/her destination with no navigational errors and in a safe manner. Actual navigation errors occur when a wrong turn is made at a navigational decision point; near navigation errors occur where there is clear indication that an incorrect turn will be taken, through the use of indicators or turning of the wheel followed by a corrective action (May & Ross, 2006).

(c) Workload

Measuring mental workload can provide an indication of the cognitive demands placed on the driver. The National Aeronautics and Space Administration Raw Task Load Index (NASA-RTLX) is appropriate to assess driver workload (Wickens, 2008). Each participant rates six components (mental demand, mental effort, physical demand, time pressure, distraction and stress level) of perceived workload on a scale from 0 to 100. The sum of the component values is divided by six to calculate the overall perceived workload score of each participant. As a score nears 100, it signifies workload is increasing.

The research took place in the Newcastle University Drive*Lab*, including equipment described in Section 2.2.

2.2. Equipment

2.2.1. Driving simulator

The study took place in Newcastle University's fixed-based ST Software Jentig50 driving simulator. Participants operated the simulator from a cabin with all the usual controls found in a car, i.e. steering wheel, pedals and gears. Five plasma screens displayed the driving scene, along with a fully simulated dashboard behind the wheel with rear view and side mirrors (see Fig. 1). This resource had proved effective in other similar studies (e.g. Guo et al., 2015).

2.2.2. Eye tracking glasses

Tobii™ eye-tracking glasses were utilised to measure visual glance behaviour. These are an unobtrusive and efficient mobile eye tracker. Each individual requires eye calibration through two cameras embedded in the glasses, so that the glasses track the pupil, which will be in a different location for each person. The glasses then record the eye movement for each participant. After completion of the experiment, data analysis took place using the Tobii™ Studio 3.2 eye-tracking software, including:

Fig. 1. Fixed-based ST Software Jentig50 driving simulator.

- Glance frequency – the number of glances made towards the route guidance display, map or roadside landmark.
- Glance duration – the duration of single glances made towards the route guidance display, map or roadside landmark.
- Glance allocation – the percentage of time in motion spent glancing towards the route guidance display, map or roadside landmark.

2.3. Participants

Participant recruitment took place through a user group created by the Social Inclusion through the Digital Economy (SiDE) project, funded through RCUK's Digital Economy programme, drawing on a representative sample of the Tyne and Wear (UK) driving population. The group was VOICE North, which utilises the experience of the older public (over 60 s) in addressing the challenges and opportunities of ageing and demographic change. The user group numbers approximately 1000, and is recruited and managed independently. However, the research team performed a full ethical approval and risk assessment. A pre-investigation questionnaire extracted demographic data and information on the participants' navigation behaviour.

The simulator investigation commenced with 40 participants. However, 10 failed to complete because of simulator discomfort. Their results were discarded. All participants were aged 60 and over, possessed a full driving licence, had been a regular driver for at least three years, had normal or correct vision and hearing and did not suffer from motion sickness. The 30 final participants were divided into three groups, with gender, navigational ability, and exposure to IVNS controlled for each group, thus allowing comparison of gender to be undertaken without the results being affected by the profile of the participants. Gender is an important consideration as there are clear navigational differences between the genders that may influence route guidance requirements and delivery modality. Women experience greater navigation-related stress and anxiety, resulting in reduced driving frequency, shorter distances, and a propensity for familiar routes (Burns, 1999; Lawton, 1994; Turano et al., 2009). Men demonstrate greater spatial confidence, but are also less likely to report any anxiety (Lawton, 1994). Research has also shown that women are more receptive to in-vehicle technologies (Yannis, Antoniou, Vardaki, & Kanellaidis, 2010).

Task order was controlled so that any differences observed were the result of the task characteristics and not the order in which they were completed. Table 2 provides a detailed breakdown of the participant profiles of each group. The table shows there is a consistency between each group for gender, average age, ownership of IVNS and experience of driving.

2.4. Procedure

The simulator test route provided a typical driving situation on an unfamiliar road network in an urban environment. It presented stable, realistic and repeatable traffic conditions that provided drivers with realistic levels of complexity to simulate how they would perform in real world navigational situations (Fig. 2). The traffic did not interact with the vehicle controlled by the participants.

The simulation also incorporated real navigational decision points with the possibility of 'getting lost'. The main theoretical underpinning for the test route was the work of Gstalter and Fastenmeier (1991), the only major study into optimum design of test routes. These should be difficult to drive and navigate, with signalled junctions, turnings across traffic, and lane changes, and drivers should perform near their limits, increasing mental demand.

The test route comprised three individual landmark-based driving scenarios:

- Audio only.
- Visual only.
- Combination of audio and visual.

These were performed in specific order for each of the three groups of participants (see Table 3).

Participants had a short break after completing each scenario. The next scenario would then proceed with a continuation of the journey. During the entire investigation, each participant would encounter 12 navigational decision points with a specific landmark, four in each of the three scenarios. The aim was to examine the impact of landmark-based information on navigation performance and information modality, rather than the quality of the landmarks used (which had been the focus of previous literature, e.g. Burnett, 1998; Burnett et al., 2001). Consequently, suitable landmarks were highlighted and incorporated into the design of the route. Previous research has proposed the most effective landmarks to use in route guidance information (Burnett, 1998). Using the previous literature and reviewing the simulator software, four landmarks were identified:

- Traffic signals.
- Pedestrian crossings.
- Petrol stations.
- Churches.

Table 2
Overview of participants in each group.

Group	Gender		Average age (years)		Presently own IVNS		Years held licence	
	Male	Female	Mean	SD	Yes	No	Mean	SD
A	5	5	69	7	5	5	47	12
B	5	5	69	7	5	5	46	12
C	5	5	71	6	5	5	51	4
Overall	15	15	69	7	15	15	48	10

Fig. 2. Driver's view in the simulator.

These landmarks possess the five key characteristics of 'good' landmarks: permanence, visibility, usefulness, uniqueness and brevity (Burnett et al., 2001).

The audio information was designed to be brief and succinct as highlighted in the literature (Burnett, 2000; May & Ross, 2006). The direction of travel was indicated first, followed by the landmark information.

Table 4 provides an overview of the four turnings that were included for each of the scenarios with a specific landmark attached. The visual screen displayed an image of the landmark that was located at the navigational decision point and an arrow indicated which way to turn. This approach adopted the icon-based display that was part of the early IVNS conceptions.

2.5. Statistical tests

Numerical data were subject to statistical testing. A Shapiro-Wilk test assessed normality. This is an appropriate test with small sample sizes. In cases when the data were normally distributed parametric tests were used. Where the data were not normally distributed, non-parametric tests were used.

For comparison of two independent groups, an Independent Sample T Test (parametric) or Man-Whitney U Test (non-parametric) was used. For comparison of two paired groups, a Paired Sample T Test (parametric) or Wilcoxon Signed-Rank Test (non-parametric) was used. For comparison of more than two paired groups, a Repeated Measures Analysis of Variance (ANOVA) (parametric) or Friedman Test (non-parametric) was used.

3. Results

3.1. Visual glance analysis of landmarks on the roadside

This section reports the glance behaviour of participants towards landmarks in the road network according to frequency, duration and allocation. The results relate to 24 participants, instead of the 30 who originally contributed. The reason for this is that eye-tracking data of six participants' data were of poor quality and consequently rejected.

Table 3
Order of scenarios performed per group.

Group	Scenario 1	Scenario 2	Scenario 3
A	Audio	Visual	Audio and visual
B	Visual	Audio and visual	Audio
C	Audio and visual	Audio	Visual

Table 4
Overview of information provided for each manoeuvre.

Manoeuvre (M)	Landmark	Information provided		
		Audio	Visual	Combination
M1 Right turn at a signalled T-junction	Traffic lights at turn	'turn right at the traffic lights'	Image of the junction with navigational arrow	Both audio and visual display
M2 Left turn from major to minor road	Petrol station	'turn left after the petrol station'	Image of the junction with the petrol station with navigational arrow	Both audio and visual display
M3 Right turn from major to minor road	Church at the side of road	'turn right after church'	Image of the junction with the church and the navigational arrow	Both audio and visual display
M4 Left turn at a signalled T-junction	Pedestrian crossing	'turn left after the pedestrian crossing'	Image of the manoeuvre with navigational arrow	Both audio and visual display

3.1.1. Glance frequency

Fig. 3 shows the mean number of glances the participants made towards a landmark on the road network. The number of glances towards the landmarks was different for each modality delivered to the participant (audio only, audio-visual, visual only). A repeated measures ANOVA determined whether there were significant differences in the number of glances made towards landmarks for the three modalities. The assumption of sphericity was violated, as assessed by Mauchly's Test of Sphericity $X^2(2) = 3.567$, $p = 0.039$ therefore a correction was applied. The method of delivering information elicited statistical changes in the number of glances, $F(1.594, 38.949) = 20.328$, $p < .05$, partial $n^2 = 0.344$. Post-hoc analysis with a Bonferroni adjustment found that there were fewer glances towards a landmark when provided with information by audio and visual combination, 1.5 (SD = 0.98), compared to audio only information, 2.8 (SD = 1.12), a statistically significant decrease of 1.3 (95% CI, 0.68–1.9), $p < .05$. There were also fewer glances towards a landmark when presented with navigational information by audio and visual combination, 1.5 (SD = 0.98), compared to visual only, 3.1 (SD = 1.12). This represented a statistically significant decrease of 1.5 (95% CI, 0.570–2.59), $p = 0.002$.

For males, a repeated measures ANOVA tested the statistical significance of the difference in glance behaviour. The assumption of sphericity was not violated, $X^2(2) = 3.481$, $p = .175$. The modality of delivering information elicited statistically significant changes in the number of glances, $F(2,22) = 5.359$, $p = .013$, partial $n^2 = 0.328$. Post-hoc analysis with a Bonferroni adjustment found that there was a statistically significant decrease in glances from receiving audio only instructions, 2.58 (SD = 1.16), compared to receiving audio and visual combination, 1.45 (SD = .99), with a statistically significant decrease of 1.25 (95% CI, 2.1–0.153), $p = .023$. In addition, there was a statistically significant decrease in glances when receiving visual only information, 3.08 (SD = 1.53), compared to audio and visual combination, 1.45 (SD = .99), a statistically significant change of 1.62 (95% CI, 3.26–.016), $p = .045$.

A similar procedure was followed for females. A repeated measures ANOVA was undertaken and the assumption of sphericity was not violated, $X^2(2) = 2.66$, $p = .265$. The modality of delivering information elicited statistically significant changes in the number of glances, $F(2,22) = 6.626$, $p = .006$, partial $n^2 = 0.376$ across all methods. Post-hoc analysis with a Bonferroni adjustment found that there was a statistically significant decrease in mean glances from receiving visual only information, 3.1 (SD = 1.55), to audio and visual combination, 1.58 (SD = 1.02), a statistically significant difference of 1.54 (95% CI, 3.1–0.118), $p < .05$. The number of mean glances decreased from audio only information, 3.08 (SD = 1.08), to audio and visual combination, 1.58 (SD = 1.02), with a statistically significant difference of 1.5 (95% CI, 2.48–0.514), $p = 0.004$.

The potential gender difference in glance frequency was not statistically significant, as assessed by an independent samples *t*-test.

3.1.2. Glance duration

Fig. 4 illustrates that participants have the shortest glance duration towards roadside landmarks when navigating with an audio and visual combination.

There was no statistically significant difference between the glance duration for each modality, as assessed by a repeated measures ANOVA. In addition, there was no statistically significant difference in modality for glance duration for gender, as assessed by repeated measures ANOVA. Moreover, independent-samples *t*-tests returned no statistically significant difference between genders for each modality.

3.1.3. Glance allocation

Fig. 5 shows that the highest percentage glance allocation at roadside landmarks occurred when participants were navigating with the visual only modality. A repeated measures ANOVA determined whether there were statistically significant differences in the glance allocation towards a landmark for the three forms of delivering navigational information. The assumption of sphericity was violated, assessed by Mauchly's Test of Sphericity, $X^2(2) = 6.635$, $p = 0.036$ therefore a correction applied. The method of delivering information elicited statistically significant changes in the number of glances, $F(1.685, 38.758) = 12.923$, $p < .05$, partial $n^2 = 0.360$. Post-hoc analysis with a Bonferroni adjustment found that glance allocation decreased from 9.67 (SD = 4.76) when navigating by visual only modality to 6.02 (SD = 4.14) with audio only instruction, a statistically significant change of 3.65 (95% CI, 6.74–0.56), $p = 0.017$. The allocation also decreased from

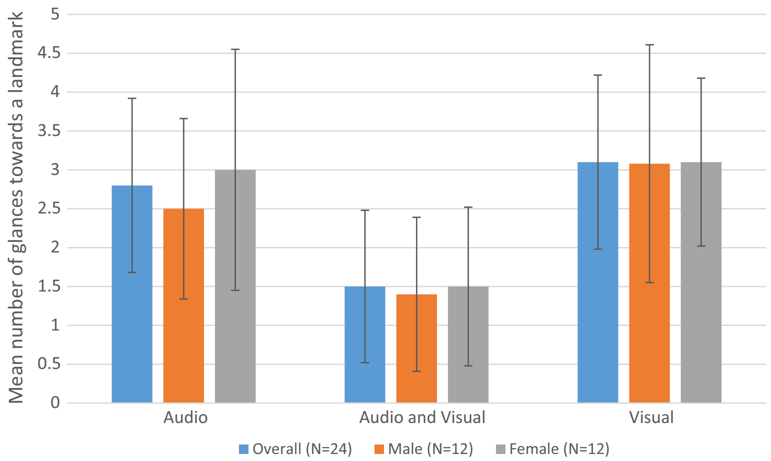

Fig. 3. Mean number of glances towards a landmark in the road network according to method of delivery.

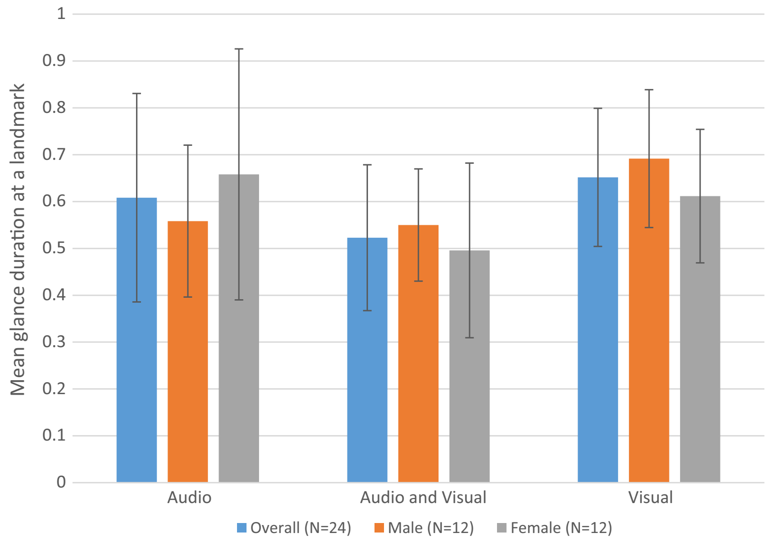

Fig. 4. Glance duration (seconds) towards physical landmark.

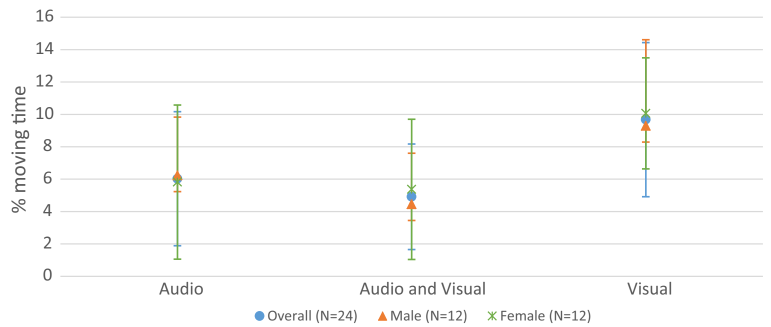

Fig. 5. Glance allocation of physical landmarks.

9.67(SD = 4.76) when navigating by visual only modality to 4.91 (SD = 3.25) with audio and visual combination, a statistically significant decrease of 4.76 (95% CI, 6.744–2.758), $p < 0.05$.

A repeated measures ANOVA determined if there was a statistically significant change in allocation between genders. Male participants' scores did not violate the assumption of sphericity, as assessed by Mauchly's Test of Sphericity $X^2(2) = 3.425$, $p = 0.180$. The method of delivering information elicited statistically significant changes in glance allocation,

$F(2,22) = 6.529$, $p = 0.006$, partial $n^2 = 0.372$. Post-hoc analysis with a Bonferroni adjustment found that glance allocation decreased from 9.29 (SD = 3.6) with visual only modality to 4.45 (S = 3.14) with audio and visual combination, a statistically significant decrease of 4.847 (95% CI, 7.79–1.893), $p = 0.002$.

Female participants' scores did not violate the assumption of sphericity, as assessed by Mauchly's Test of Sphericity $X^2(2) = 2.696$, $p = 0.260$. The method of delivering information elicited statistically significant changes in glance allocation, $F(2,22) = 6.271$, $p = 0.007$, partial $n^2 = 0.363$. Post-hoc analysis with a Bonferroni adjustment found that glance allocation decreased from 10.06 (SD = 4.33) with visual only modality to 5.37 (SD = 3.14) with audio and visual combination, a significant decrease of 4.69 (95% CI 8.06–1.31), $p = 0.007$.

There was no statistically significant difference between the genders for each delivery method, as assessed by independent-samples *t*-tests.

3.1.4. Visual glance analysis for roadside landmarks: Key findings

- The combination of audio and visual navigational information resulted in the lowest glance frequency and allocation for older drivers. This means that this combination allowed the drivers to find the roadside landmark with the least impact on visual behaviour.
- The visual glance analysis did not provide any statistically significant difference between the genders.

3.2. Navigational errors

When the participants followed the visual only information, the highest number of navigational errors resulted. The number of navigational errors is seen to drop dramatically when landmark information is delivered through audio only instruction and the combination of audio and visual.

A repeated measure ANOVA determined whether there were statistical differences in navigational errors over the three forms of information delivery. Post-hoc analysis with a Bonferroni adjustment revealed that relying on audio only instruction resulted in a statistically significant decrease in navigation errors compared to the visual only modality (1.5 (95% CI, 2.215–0.785) $p = .001$). When using the audio and visual combination this resulted in statistically significantly fewer navigational errors compared to the visual only modality (1.367 (95% CI, 2.091–0.642) $p = .001$).

Thus, the audio only and the combination of audio and visual produced the lowest number of navigational errors. Females benefited with statistically significantly confidence when landmark-based route guidance information was provided.

3.3. Workload

This section focuses on the results from the NASA-RTLX questionnaire. The lowest perceived workload was reported when the participant received audio only instruction (22.5, SD = 16.7). However, participants reported the audio and visual combination to be only marginally higher (23.1, SD = 18.5).

There was a statistically significant decrease in workload from the visual only modality to the audio only and combination of audio and visual. The workload score decreased from 36.1 when using the visual only modality to 22.5 when using the audio only instruction (13.583 (95% CI, 9.146–18.020) $p = .001$), and to 23.1 when using the audio and visual combination (13.083 (98% CI, 8.769–17.398) $p = .001$).

Table 5 displays the overall scores of each component of the NASA-RTLX for the three modalities of information delivery.

Females scored the workload higher for each modality compared to males. For males, post-hoc analysis with a Bonferroni adjustment revealed that workload scores were significantly different between:

- Visual only 35.22 (SD = 25.7) to audio only 21.5 (SD = 17), a decrease of 13.67 (95% CI, 20.90–6.42), $p = .001$.
- Visual only 35.22 (SD = 25.7) to audio and visual combination 19.77 (SD = 15), a decrease of 15.44 (95% CI, 22.13–8.75), $p = .001$.

Table 5
Mean and standard deviation scores of each component of the NASA-RTLX across all modalities (plus mean overall scores).

	Audio ($N = 30$)	Visual ($N = 30$)	Audio and visual ($N = 30$)
Mental demand	27 (20)	46 (26)	28 (24)
Mental effort	29 (23)	50 (29)	29 (24)
Physical demand	19 (14)	23 (14)	20 (19)
Time pressure	16 (13)	23 (15)	17 (15)
Distraction	19 (13)	37 (25)	20 (14)
Stress level	26 (19)	33 (26)	24 (19)
Overall	23 (17)	36 (18)	23 (17)

The findings from the male repeated measures ANOVA indicated that the audio only and the audio and visual combination statistically significantly reduce the workload of the driver. Post-hoc analysis with a Bonferroni adjustment revealed that workload scores were statistically significantly different between:

- Visual only 37.056 (SD = 25.40) to audio only 23.556 (SD = 16.35), a decrease of 13.5 (95% CI, 18.849–8.151), $p = .001$.
- Visual only 37.056 (SD = 25.4) to audio and visual combination 26.33 (SD = 25.4), a decrease 10.7 (95% CI, 16.288–5.156), $p = .001$

The findings from the female participants echoed that of the males. The audio only and the audio and visual combination statistically significantly reduce the perceived workload. The key findings are that the workload scores were statistically significantly lower when the navigational information was delivered through audio only instruction.

4. Discussion

Building on the authors' previous work (Emmerson et al., 2013), older drivers participated in a driving simulator-based investigation to study navigation performance using landmark-based route guidance information. The landmark-based information was presented in three modalities: audio only, visual only, and a combination of audio and visual formats.

Visual glance behaviour, navigational errors and workload were assessed to compare older drivers' navigational performance, to determine the most appropriate mode of information delivery, and to ascertain any potential gender differences.

4.1. Visual glance behaviour

The three scenarios required the participants to be fully reliant on the landmark-based information provided *en route*.

The audio and visual combination was the least visually demanding modality. It scored the lowest glance allocation percentage, lowest glance duration scores, and the second lowest mean glance frequency. The visual only modality resulted in a high visual demand for participants. The results provide an indication that landmark-based route guidance information does not adversely affect older drivers' visual behaviour if the information is delivered through a combination of audio and visual instruction. The participant's glance frequency, duration and allocation were all greater when they navigated with just the visual display. This supports the findings of earlier studies such as May et al. (2005).

Female participants glanced more frequently for all three modalities compared to males. The results suggest that providing landmark-based route guidance information does not adversely affect older drivers' visual behaviour if the information is presented through a combination of audio and visual instruction.

4.2. Navigational errors

Visual only information produced the highest number of navigational errors. Participants were six times more likely to commit a navigational error with the visual only modality compared to audio and visual combination. The benefit of receiving information via audio only instruction or audio and visual combination is reported in the literature (Hölscher, Tenbrink, & Wiener, 2011; Liu, 2001).

4.3. Workload

Landmarks appear to be a good format through which to deliver navigational information to older drivers. They require less concentration, which is attributable to the selected landmarks being 'good' (Burnett et al., 2001), whilst landmarks form a natural part of an individual's cognitive map.

The use of audio only instruction or an audio and visual combination would give the lowest workload to drivers. The visual only modality resulted in significant issues in visual glance behaviour, navigational errors and workload.

4.4. Recommendations for future IVNS for older drivers

The research described in this paper has produced findings that enable the authors to present recommendations regarding the functionality of future IVNS for older drivers.

IVNS must become much more user-friendly for older drivers. Measures should include provision of landmarks to assist older drivers successfully navigate a journey. This appears to support the findings of the literature (e.g. May et al., 2005). Elements of 'street view' could even be included along with context-specific or point of interest (POI) information. In connection with this, a range of audio voiceovers would be a positive feature. The preference of audio- or audio-visual combination modalities appears to validate other research in this area (Jensen et al., 2010; Moldenhauer & McCrickard, 2003). One possible drawback is maintaining the database of landmarks as an up-to-date representation of the streetscape.

IVNS could additionally provide audible indication of upcoming changes to the speed limit, or for the application of intelligent speed control (Guo et al., 2015), and could 'bring the road sign into the car' by providing an image of a forthcoming sign on the display, thus giving greater time to adjust. In terms of format for information delivery, *the research shows that a combination of audio and icon-based visual display may provide the most user-friendly approach for older drivers*.

4.5. Future navigation for older drivers

Although not directly deriving from the research reported in this paper, it is clear that older drivers' navigation would also benefit from detail and flexibility at the pre-trip planning level. This would include potential for a more detailed breakdown of a planned route: e.g. different class of road, category of junction (e.g. signalised or not), decision points (with images), an option to 'virtually' drive route sections, number of right turns at non-signalised junctions, and landmarks. Re-programming a route to avoid certain features should also be possible. In a similar vein, programming a route for characteristics other than length or duration should also be possible; many older drivers travel for leisure and value other characteristics, such as scenic routes or POI information. Finally, there is potential to bring pre-trip planning into the vehicle via a personal device (PC or tablet), transferring it to the IVNS, thus permitting the planned trip to become the guided trip.

4.6. Limitations of the research and future research areas

(a) Use of driving simulator

A driving simulator was utilised in this study. Future research in this area would benefit from extension to a real-world trial. This would allow for a longer experimental drive with a greater degree of complexity in the route undertaken, allowing real-world observation of older drivers' navigation behaviour. Such a study might investigate the efficacy of landmark-based route guidance combined with icon-based screen and audio instructions. A real-world trial provides opportunity for a larger sample of participants, providing better representation of society.

(b) Information modality

Further research is required to assess the benefits of an icon-based display, such as the one implemented in this investigation, compared to a moving map display for older drivers.

Audible landmark information is very effective at navigating older adults; however, it is essential to consider provision of information that is fully audible for older drivers.

Use of a heads-up display (HUD) may possess the potential to remove many of the current visual difficulties older drivers have with IVNS. The advantage of an HUD for older adults would be the reduced need to focus rapidly between near and far objects. The information presented can include real-time data and contextual information for that particular journey (Akamatsu, Green, & Bengler, 2013; Huang, Chao, Tsai, & Hung, 2013), this is another important future area for research.

(c) Landmarks

The availability of effective landmarks on the road network requires consideration. The driving simulator environment allowed location of proven effective landmarks at each navigational decision point. Research is required to identify the availability of suitable landmarks on the road network. Furthermore, consideration is required when choosing the landmarks as to their permanence.

(d) Driver safety

Although safety is an important outcome of effective navigation, the focus of the paper is on older drivers' navigational performance when provided with landmark-based route guidance information, and the most appropriate method of delivering landmarks within the route guidance information. Driver safety, for instance distraction and lane deviation, was beyond the scope of this study and is a prioritised area of focus in the next phase of the research. This paper also investigated gender as an indicator of navigational performance. Future research will look in detail at age, which is a key indicator of safety.

5. Conclusion

This paper presents a study of older drivers' interaction with IVNS utilising a driving simulator investigation, and building on previous work by the authors (Emmerson et al., 2013). The investigation studied drivers' navigational performance when provided with landmark-based route guidance information, and different information delivery modalities (audio only, visual only, and a combination of audio and visual).

There are clear benefits for older drivers from using IVNS, especially helping them undertake journeys with which they are less comfortable or familiar. However, existing IVNS presents challenges to usability (touch screens for programming, moving-map displays) (Emmerson et al., 2013). The result is that many older drivers are resistant to IVNS and rely excessively on pre-trip planning. Consequently, this demographic self-regulates when driving, leading to a reduction in car-based mobility. New design solutions are therefore necessary.

These should include use of 'good' landmarks, although what constitutes 'good' may vary by geographic location. This investigation has shown that these have the potential to be an effective method of navigating older drivers, in particular at decision points, and for locating drivers in an environment. Their use reduces navigational errors and results in a lower workload. In the simulator trial, 97% of the participants rated landmarks as easy to follow.

A second, connected, solution is the modality for delivering information via IVNS. A combination of audio and visual is the preferred format. This modality also reduces the hazard of distraction by roadside landmarks resulting in fewer visual glances and lower glance duration to the roadside compared to other modalities.

These solutions result in a lower workload and fewer navigational errors. Delivery through a visual only format increases workload, navigational errors and visual demand. This is despite the fact that the visual format used in this investigation was icon-based, which older drivers prefer to the conventional moving-map display (Emmerson et al., 2013).

The investigation observed possible gender differences. Older females are more willing to discuss navigational difficulties than males and are more receptive to the use of landmarks as a navigational tool.

In conclusion, future IVNS should seek to accommodate older drivers' needs through landmark-based information delivered in a combination of audio and icon-based visual display formats. Design and provision of IVNS tailored to older drivers' needs can make a considerable contribution to maintaining individual mobility for longer.

Acknowledgements

The authors are grateful to the Research Councils' UK Digital Economy programme for funding the SiDE Digital Economy Hub project (EP/GO66019/1), and the Engineering and Physical Sciences Research Council 'Telling Tales of Engagement' project (EP/KO37579/1).

References

Akamatsu, M., Green, P., & Bengler, K. (2013). Automotive technology and human factors research: Past, present, and future'. *International Journal of Vehicular Technology*.

Banister, D., & Bowling, A. (2004). Quality of life for the elderly: The transport dimension. *Transport Policy, 11*(2), 105–115.

Birrell, S. A., & Young, M. S. (2011). The impact of smart driving aids on driving performance and driver distraction. *Transportation Research Part F: Traffic Psychology and Behaviour, 14*(6), 484–493.

Bryden, K. J., Charlton, J. L., Oxley, J. A., & Lowndes, G. J. (2013). Self-reported wayfinding ability of older drivers. *Accident Analysis & Prevention, 59*, 277–282.

Burnett, G. E. (1998). *Turn right at the King's Head': Drivers' requirements for route guidance information*. UK: Loughborough University of Technology.

Burnett, G.E. (2000). Usable vehicle navigation systems: Are we there yet? In *Vehicle electronic systems. 29–30 June European conference and exhibition* (pp. 3.1.1–3.1.11).

Burnett, P., & Lucas, S. (2010). Talking, walking, riding and driving: The mobilities of older adults. *Journal of Transport Geography, 18*(5), 596–602.

Burnett, G. E., Smith, D., & May, A. J. (2001). Supporting the navigation task: Characteristics of 'good' landmarks. *Proceedings of the annual conference of the ergonomics society*, 441–446.

Burns, P. C. (1999). Navigation and the mobility of older drivers. *Journals of Gerontology – Series B Psychological Sciences and Social Sciences, 54*(1).

Cairns, P., & Cox, A. L. (2008). *Research methods for human-computer interaction*. Cambridge University Press.

Charlton, J. L., Oxley, J., Fildes, B., Oxley, P., & Newstead, S. (2003). Self-regulatory behaviours of older drivers. *Annual proceedings/association for the advancement of automotive medicine. Association for the advancement of automotive medicine* (Vol. 47, pp. 181–194). .

Chown, E., Kaplan, S., & Kortenkamp, D. (1995). Prototypes, location, and associative networks (PLAN): Towards a unified theory of cognitive mapping. *Cognitive Science, 19*(1), 1–51.

Daimon, T., & Kawashima, H. (1995). New viewpoints of evaluation of in-vehicle information system — Applying methods in cognitive engineering. *JSAE Review, 16*(3), 318.

Dalton, P., Agarwal, P., Fraenkel, N., Baichoo, J., & Masry, A. (2013). Driving with navigational instructions: Investigating user behaviour and performance. *Accident Analysis & Prevention, 50*, 298–303.

Emmerson, C., Guo, W., Blythe, P. T., Namdeo, A., & Edwards, S. (2013). Fork in the road: In-vehicle navigation systems and older drivers. *Transportation Research Part F: Traffic Psychology and Behaviour, 21*, 173–180. http://dx.doi.org/10.1016/j.trf.2013.09.013.

Forlizzi, J., Barley, W. C., & Seder, T. (2010). Where should I turn: Moving from individual to collaborative navigation strategies to inform the interaction design of future navigation systems. In *Proceedings of the 28th international conference on human factors in computing systems* (pp. 1261–1270). ACM.

Green, P. (1993). Measures and Methods used to assess the safety and usability of driver information systems. *Final Report Transportation Research Institute (UMTRI)*.

Gstalter, H., & Fastenmeier, W. (1991). *Safety Impacts of In-Car Navigation Systems* Munchen (DRIVE I V1017 BERTIE, Deliverable 69). Munich, Germany: Bayerische Motorenwerke AG.

Guo, W., Blythe, P. T., Edwards, S., Pavkova, K., & Brennan, D. (2015). Effects of intelligent speed adaptation technology on older drivers' driving performance. *IET Intelligent Transport Systems, 9*(3), 343–350.

Guo, A. W., Brake, J. F., Edwards, S., Blythe, P. T., & Fairchild, R. G. (2010). The application of in-vehicle systems for elderly drivers. *European Transport Research Review, 2*(3), 165–174.

Hölscher, C., Tenbrink, T., & Wiener, J. M. (2011). Would you follow your own route description? Cognitive strategies in urban route planning. *Cognition, 121*(2), 228–247.

Huang, C.-H., Chao, C.-W., Tsai, T., & Hung, M.-H. (2013). The effects of interface design for head-up display on driver behavior. *Life Science Journal, 10*(2).

Iaria, G., Palermo, L., Committeri, G., & Barton, J. J. S. (2009). Age differences in the formation and use of cognitive maps. *Behavioural Brain Research, 196*(2), 187–191.

Ishikawa, T., Fujiwara, H., Imai, O., & Okabe, A. (2008). Wayfinding with a GPS-based mobile navigation system: A comparison with maps and direct experience. *Journal of Environmental Psychology, 28*(1), 74–82.

Jensen, B. S., Skov, M. B., & Thiruravichandran, N. (2010). Studying driver attention and behaviour for three configurations of GPS navigation in real traffic driving. In *Proceedings of the ACM conference on human factors in computing systems (CHI'10)*. .

Kim, S., Hong, J.-H., Li, K., Forlizzi, J., & Dey, A. (2012). Route guidance modality for elder driver navigation. *Pervasive Computing*, 179–196.

Kim, M., & Son, J. (2011). On-road assessment of in-vehicle driving workload for older drivers: Design guidelines for intelligent vehicles. *International Journal of Automotive Technology, 12*(2), 265–272.
Kitchin, R. M. (1994). Cognitive maps: What are they and why study them? *Journal of Environmental Psychology, 14*(1), 1–19.
Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles, 30*(11), 765–779.
Liu, Y. C. (2001). Comparative study of the effects of auditory, visual and multimodality displays on drivers' performance in advanced traveler information systems. *Ergonomics, 44*(4), 425–442.
Liu, I., Levy, R. M., Barton, J. J. S., & Iaria, G. (2011). Age and gender differences in various topographical orientation strategies. *Brain Research, 1410*, 112–119.
Lynch, K. (1960). *The image of the city* (24th ed.). Cambridge, Massachusetts: The Technology Press and Harvard University Press.
May, A. J., & Ross, T. (2006). Presence and quality of navigational landmarks: Effect on driver performance and implications for design. *Human Factors, 48*(2), 346–361.
May, A., Ross, T., & Osman, Z. (2005). The design of next generation in-vehicle navigation systems for the older driver. *Interacting with Computers, 17*(6), 643–659.
Metz, D. H. (2000). Mobility of older people and their quality of life. *Transport Policy, 7*(2), 149–152.
Metz, D. (2003). Transport policy for an ageing population. *Transport Reviews, 23*(4), 375–386.
Moldenhauer, D., & McCrickard, S. (2003). *Effect of information modality on geographic cognition in car navigation systems*. Center for HCI and Department of Computer Science, Virginia Tech.
Musselwhite, C., & Haddad, H. (2010). Exploring older drivers' perceptions of driving. *European Journal of Ageing, 7*(3), 181–188.
Nothegger, C., Winter, S., & Raubal, M. (2004). Selection of salient features for route directions. *Spatial Cognition and Computation, 4*(2), 113–136.
Pak, R., Czaja, S. J., Sharit, J., Rogers, W. A., & Fisk, A. D. (2008). The role of spatial abilities and age in performance in an auditory computer navigation task. *Computers in Human Behavior, 24*(6), 3045–3051.
Rabbitt, P., Carmichael, A., Jones, S., & Holland, C. A. (1996). *When and why older drivers give up driving*. AA Foundation for Road Safety Research.
Rockwell, T.H. (1988). Spare visual capacity in driving-revisited: New empirical results for an old idea. *Vision in Vehicles II. Second International Conference on Vision in Vehicles*.
Roger, M., Bonnardel, N., & Le Bigot, L. (2011). Landmarks' use in speech map navigation tasks. *Journal of Environmental Psychology, 31*(2), 192–199.
Turano, K. A., Munoz, B., Hassan, S. E., Duncan, D. D., Gower, E. W., Roche, K. B., ... West, S. K. (2009). Poor sense of direction is associated with constricted driving space in older drivers. *Journals of Gerontology – Series B Psychological Sciences and Social Sciences, 64*(3), 348–355.
Wickens, C. D. (2008). Multiple resources and mental workload. *Human Factors, 50*(3), 449–455.
Yamamoto, N., & DeGirolamo, G. J. (2012). Differential effects of aging on spatial learning through exploratory navigation and map reading. *Frontiers in Aging Neuroscience, 4*(Jun), 1–7.
Yannis, G., Antoniou, C., Vardaki, S., & Kanellaidis, G. (2010). Older drivers' perception and acceptance of in-vehicle devices for traffic safety and traffic efficiency. *Journal of Transportation Engineering, 136*(5), 472–479.
Zhang, L., Wang, B., Jia, H., & Dong, B. (2012). Study on the adaptability of on-board navigation equipment for older people. In *Proceedings of the 12th COTA international conference of transportation professionals, Beijing* (pp. 1107–1114).